

II. *A Discourse concerning some Influence of Respiration on the Motion of the Heart, hitherto unobserved.* By J. Drake, M. D. F. R. S.

THO divers accurate Treatises of the *Heart*, and its action, have been written by Learned Men of several Nations, especially by two of our own Country; the Great *Dr Harvey*, to whose happy Sagacity this Nation owes the Glory of the Invention of the *Circulation* of the *Blood*; and the incomparable *Dr Lower*, to whom we are beholding for a compleat display of the *Mechanical Structure* of the *Heart*, and a most ingenious Rationale of its Action. Yet there remain several doubts and difficulties about it (in my opinion) not sufficiently accounted for, towards the resolving some of which I shall offer what my own thoughts have suggested to me, and leave it to the consideration of the Reader.

The Learned *Dr Lower* (whose accurate piece on this Argument will insure his Reputation so long as Physical knowledge shall last in esteem) has so well accounted for the *Systole*, or Contraction of the Heart from the *Mechanical Structure* of it, that he seems almost to have exhausted the subject, and had he been as happy in discovering the true cause of the *Diastrale*, he had left little room for the Industry and Sagacity of others about this *Viscus*.

But having judiciously and solidly explain'd the *Systole*, he contents himself to ascribe the *Diastrale* to a motion of *Restitution*, which account gives me no satisfaction: Because the *Systole* being the proper, and (as himself confesses) the only motion of the Heart, a state of *Contraction* seems to be the natural state, and consequently without external violence, it shou'd have no *Diastrale* at all.

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This will appear more plain, if we consider the circumstances of it, and its motion, as a Muscle, with respect to other Muscles. That Contraction is the proper Action, and state of all Muscles, is evident from Experience of Fact, as well as Reason. For, if any Muscle be freed from the power of its *Antagonist*, it is immediately contracted, and is not by any action of the Will, or Spirits to be reduc'd to a state of *Dilatation*. Thus, if the *Musculi Flexores* of any Joint be divided, the *Extensores* of that Joint being by that means freed from the contrary Action of their *Antagonists*, that Joint is immediately extended without any consent of the Will, and in that state it remains; and so *Vice versa* if the *Extensores* be divided. From whence it is plain, that the Muscles have no restitutive motion, but what they derive from the Action of their *Antagonists* by which they are ballanc'd. Thus likewise the *Sphincters* of the *Gula*, *Anus* and *Vesica*, having no proper *Antagonists*, are always in a state of Contraction, and suffer nothing to pass 'em, but what is forced thro' em by the contrary Action of some stronger Muscles, which, tho' not properly to be call'd *Antagonists*, yet on all necessary occasions perform the office of such.

That the Heart is a Muscle, furnish'd and instructed for motion like other Muscles, is (in my opinion at least) demonstrated beyond contradiction by Dr *Lower* and others. And, as it is a *Solitary* Muscle without any proper *Antagonist*, and not directly under the power of the Will, nor exercising *Voluntary* motion, it approaches nearest to the *Sphincter* kind, which only has these conditions in common with it. But in constant and regular alternations of Contraction and Dilatation, it differs exceedingly from all the Muscles of the Body.

This reciprocal *Æstus* of the Heart has given the Learned abundance of trouble; who, finding nothing peculiar in the structure, which should necessarily occasion it, nor any

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Antagonist, whose re-action shou'd produce it, have been extremely perplexed to find out the cause of it.

But passing over the various opinions of Authors, to avoid being tedious, I shall take notice here only of the very Learned Dr *Lower's*, in whose account of the *Systole*, however solid and ingenious, I observe something deficient, and whose *Hypothesis* of the *Diaſtole* I think to be precarious and false.

This excellent Author, having by sound Arguments, drawn from the Structure and Mechanism of the Heart, establisht the certainty of its *Muscular* Motion, rests satisfied, without taking notice of any Assistance, that the Heart receives from any other Part, except from the Brain, by the means of the eighth Pair of Nerves.

The Accurate *Borellus* in his *Oeconomia Animalis* computes the *Motive* Power of the *Machine* of the Heart to be equal to, or to surmount that of a Weight of 3000 *l*. The *Obstacles* to the Motion of the Blood thro the *Arteries* he esteems equivalent to 180,000 *l*. which is 60 times as much as he rates the Force of the Heart at. Then deducting 45,000 *l*. for the Adventitious Help of the *Muscular Elastick Coat* of the *Arteries*, he leaves the Heart with a Force of 3,000 *l*. to overcome a resistance of 135,000 *l*. that is, with 1 to remove 45. Part 2d.
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This stupendous effect he contents himself to ascribe to the *Energy* of *Percussion*. But, had he proceeded in his Calculation to the Veins, which he allows to contain constantly a quantity of Blood, quadruple to the Contents of the Arteries, and to which this *Energy* of *Percussion* does either not reach at all, or but very languidly, he might probably have seen a necessity for some other Expedient to remove so insuperable a difficulty.

But not to insist rigorously on the exactness of this Calculation (tho the great Abilities of the Author in this way, and his Ingenuity and Modesty, are a sufficient Warrant for the accuracy of his Computations, and the fidelity of his Accounts) we may allow a much greater Deduction, than

would be justifiable, without lessening the difficulty. But this account I have taken notice of purely for the sake of the Calculation, which may be of use in the Sequel, the account it self being in other respects more defective than Dr *Lower's*, to which we will return.

The Dr, notwithstanding his great Sagacity, appears (to me) to have overlookt something of very great moment, and importance in the explication of the Action of the Heart. For, tho it shou'd be granted, that the *Muscular Fibres* of the Heart acted by the Nerves, are the immediate Instruments of its *Constriction* or *Systole*, yet it must not be denied, that the *Intercostal* Muscles and *Diaphragm* are of great service to aid and facilitate this Contraction, by opening a Passage for the Blood thro the Lungs, which denied wou'd be an invincible obstacle.

Neither do they promote it that way only. The manner how they fartherassist the Heart in its Contraction, will appear manifestly, if we consider the different Posture, Situation and Capacity of the Blood Vessels of the Lungs in the several times of *Elevation* and *Depression* of the *Costæ*.

The *Pulmonary Artery* rises from the *right Ventricle* of the Heart, and runs in one Trunk, till it comes to the *Aspera Arteria*, where it is divided, and sends a Branch along with each division of the *Aspera Arteria*, according to all the minutest subdivisions, of which it is likewise subdivided, accompanying all the *Bronchi*, in their whole progress thro the Lungs.

The *Pulmonary Vein*, which empties it self into the *Left Ventricle* of the Heart, spreads it self on the *Aspera Arteria* and *Bronchi*, in the same manner that the Artery does.

The necessary consequence of this disposition is, that this Artery and Vein being coextended with, and fasten'd to the *Bronchi*, must needs suffer such alteration of *Superficial Dimensions*, as the *Bronchi* do in the *Elevation* or *Depression* of the *Costæ*.

While the Ribs are in a state of *Drepression* (whether before Commerce with the external Air or after) the *Annular Cartilages* of the *Bronchi* shrink one into another, and by that

that means their *Dimensions* are exceedingly contracted. In conformity to this condition of the *Bronchi* the *Pulmonary Artery* and *Vein* must likewise, either by means of their *Muscular Coats* contract themselves to the same *Dimensions*, or lye in *Folds* or *Corrugations*, which is less probable.

On the other hand, when the *Ribs* are elevated, and the *Diaphragm* bears downward, the *Air* rushing into the *Lungs*, shoots out the *Cartilaginous Rings*, and *Divaricates* the *Branches* of the *Trachea*, and by them extends and divaricates the several divisions of the *Pulmonary Artery* and *Veins*, and thereby lengthens and enlarges their *Cavities*.

This enlargement of their *Cavities* is very considerable, not only upon the score of the addition, which they receive in length thereby, but also upon the account of their *Divarication*. For whereas, when the *Ribs* are depressed, and the *Lungs* subside, the *Blood Vessels* are not only contracted, (as I have already observ'd) but their *Branches*, which are exceeding numerous, approach one another, and lie in juxtaposition, by which their *Cavities* are very much compress'd and streighten'd : when the *Ribs* are elevated, and the *Lungs* turgid with *Air*, not only the *Fibres*, by which their *Coats* in the opposite State were contracted, are extended, but those innumerable *Vessels*, which lying before in lines almost parallel upon one another, compress'd one another, making an *acute Angle* at their *Junctures*, are divaricated and separated from each other, and make an *obtuse*, whereby their *Channels* are widen'd.

Thus a passage is open'd to the *Blood*, from the *Right Ventricle* of the *Heart* to the *Left*, thro the *Lungs*, to which it cou'd not otherwise pass ; and the opposition, which the *Blood*, contain'd in that *Ventricle*, must otherwise necessarily have made to its constriction, is taken off, and the *Systole* thereby facilitated.

Nor is that all. For the *Diastole* being caus'd (as I shall in the sequel shew) by the Force of the *Blood* rushing into the *Ventricles*, this Ampliation and Extension of the *Pul-*
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monary Artery is a sort of *Check* or *Counterpoise* to it, and prevents an endeavour towards two contrary Actions at once, which must necessarily frustrate both. For the Heart being a *Springy*, *Compressible* Body, whose proper Action, which is Contraction, depends on the influx of certain Fluids into its Fibres, or Substance; and containing besides a Fluid in its *Ventricles*, or great Cavities, in one of which is the Mouth of this Artery, the action of this Vessel must in great measure resemble that of a *Syringe*, whose extremity is immers'd in Water, the Enlargement or Expansion of the Channels of the Artery answering the drawing of the *Embolum*, as the Constrictive Motion of the Muscle of the Heart does the Pressure of the *Atmosphere* upon the Surface of the Water, the one making way for the fluid, and the other forcing it to follow, where the resistance is least. In this sense we may allow a sort of Attraction to the *Pulmonary* Artery, depending wholly upon the Action of the *Intercostal* Muscles and *Diaphragm*, which we must therefore confess to be very servicable and instrumental in promoting the *Systole* of the Heart.

But if the Learned Author be deficient in his account of the *Systole*; that is, if he has not observ'd all the Mechanism and Contrivance of Nature for the Contraction of the Heart; much less sufficiently has he accounted for the *Diastole*, or Dilatation of it, which he ascribes to a Motion of *restitution* of the over-strain'd Fibres, which yet he confesses are made for *Constriction* only. 'Tis true, he immediately after joyns the *influx* of the *Blood* as a concurrent cause; but from the slight notice that he takes of it, 'tis plain, that he did not so much as dream of any great share it had in that action. His words are these.

Quin & (ut obiter hoc moneam) cum omnis motus contractionis perficiatur, & Cordis Fibre ad constrictionem solum factæ sint, apparet quoque Cordis motum totum in Systole positum esse; cumq; Fibre ultra tonum suum in omni constrictione ejus tendantur, idcirco ubi nixus iste absolvitur, motu quasi restitutionis Cor iterum

iterum relaxatur, & sanguine a Venis influente rursus distenditur ; a nullo enim cordis motu, nisi tensionem suam remittente, & ab irruente sanguine Diastole ejus libratis adco viribus succedit.

I have transcribed the entire Paragraph, because it contains his whole *Hypothesis* of the *Diastole*, and all the notice that he takes of it thro his whole Work. But how slender soever this may prove, it is the most substantial that I have any where met with, except a late one of Mr *Cowper*, which is properly an improvement of this, and shall be considered in the sequel.

But, if Contraction be the sole Action of these Fibres (as this Great Man confesses it to be) and as indeed it is of all *Muscular* Fibres, I wonder how so judicious a Writer came to slip into such an absurdity, as to call their Distension (vulgarly but improperly called Relaxation) a Motion of *Restitution*. For from the Nature of those Fibres, and their disposition in the Structure of the Heart, the Natural State of the Heart appears manifestly to be *Tonical*, and its Dilatation a State of Violence ; and consequently the Constriction is the *true* motion of *Restitution*, and the State to which it will *spontaneously* return, when the Force is taken off, which is the work of the *Intercostal* Muscles and *Diaphragm*.

Thus we are left still to seek for the true cause of the *Diastole*, which seems to me to be the main and most difficult *Phænomenon*, relating to the Heart and the Circulation of the Blood. But in Mr *Cowper*'s ingenious *Introduction* to his *Anatomy of Human Bodies*, I find the Share which Dr *Lower* hints the Blood to have in that Action, further prosecuted, and improv'd into the main Instrument of the Dilatation of the Heart, wherein I agree entirely with him. But as to the manner, and reasons of its being so very Instrumental, I can't be so perfectly of his mind.

The Heart (says this accurate Anatomist) *of an Animal* bears a great Analogy to the *Pendulums* of those Artificial

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Automata, Clocks and Watches, whilst its Motion is performed like that of other Muscles, the Blood doing the Office of a Pondus.

This Explication, being but a Simile without a distinct application to particulars, is beside so very short, that I can at best but give a conjecture at the meaning, which if I mistake, I shall deserve to be excused, and expect to be better inform'd.

By the *Blood's* doing the Office of a *Pondus*, I suppose he means, that the Blood contributes in the same manner to the Motion of the Heart, as the *Weights* do to that of the *Pendulum* of a *Clock*. If so, the Blood, according to him, must be the Instrument of *Constriction*; and *Dilatation* must be the *Natural* State, or *Spontaneous* Motion, to which it wou'd, when under no Violence, return; the contrary of which, I presume, will appear ere I have done.

But if he means, that the *Blood* in its reflux, by *gravitating* on the *Auricles* and *Ventricles*, dilates and expands 'em, acting therein as a *Counterpoise* to its contraction as a Muscle, I cou'd wish his design had not bound him up to so narrow a compass, and that he had given us an explication at large of so abstruse and so important a *Phenomenon*. Because the *Specifick Gravity* of the Blood seems to me a cause by no means alone adequate to the effect, which it is here suppos'd to produce.

For, if the Blood acts only as a *weight* by meer *gravitation*, then that part of it only which descends from the Parts above the Heart can be employ'd in that action. This at the largest computation can't amount to five pound weight, and must, according to the computation of *Borellus*, force a Machine, that is able to overcome a resistance of 135,000*l*. I leave every man to deduct what he shall upon examination find reasonably to be deducted, and yet shall rest secure, that it is not to be effected in the least with so small a Weight.

But neither does the *Refluent* Blood gravitate in any such proportion, as I have here assign'd. For to make a true estimate of its *Gravitation*, we must consider the circumstances of the Liquor suppos'd to gravitate; in which it very much resembles Water inclos'd in a recurve Tube, of which, if the length of the two Legs be equal, it may be suspended in the Air full of Water, with the Extremities downwards, without losing a drop, altho the *Diameter* of those Legs shou'd be very unequal. The Case of the Arteries and Veins is pretty near a parallel to a Tube, so fill'd and inverted. For, if the Arteries and Veins be continued Tubes, (as by the Microscope they are made to appear) then supposing their contents to have no other determination of Motion, than their own weight wou'd give 'em, the contain'd Fluids must be counterpoises to each other. For the Veins and Arteries being join'd at the smaller extremities, and the larger of both terminating in the same Parallel Line, it is impossible, according to the Laws of *Hydrostatics*, that the contents of either shou'd overballance t'other. How far then must it fall short of forcing the natural Power and Resistance of so strong a Muscle as the Heart, by meer Gravitation.

The Blood indeed has a *Progressive* Motion thro its Vessels, wherein it differs from Water, in a recurve Tube, in the experiment above stated. But, if the natural Gravitation of the Blood contributes nothing to the Dilatation of the Heart, this *Progressive* Motion will not be found much more sufficient. For, as this Motion is deriv'd entirely from the Heart's Constriction (as all accounts hitherto derive it) cou'd the Blood be suppos'd to re-act upon the Heart, with all the force first impress'd upon it by the Heart, it wou'd be insufficient, unless we will suppose the *Force communicated* to be superiour to the *Power Communicant*, which is absurd.

But when the just and necessary Deductions for the Impediments, which the Blood meets with in its Progress

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thro the Vessels, shall be made, the remaining Force will be found so exceeding weak, that to prop the Blood thro the Veins may be a task alone too great for so small a Power, without charging it with the additional difficulty of forcing the Muscle of the Heart.

Alphonsus Borellus, after a great deal of solemn pains taken to shew his care and exactness, and to possess his Reader of the truth of his Calculations, casts up the Force of the Heart, and the *Muscular Coat* of the Arteries, to be together equal to a weight of 3,750 *l.* and allots 'em a Resistance equal to 180,000 *l.* to overcome which is 45 to 1: To make up for a disproportion, by his own confession, incredible to those who have not considered the matter as he had done, he flings into the Scale the additional *Force of Percussion*, which he leaves *indefinite*, and thinks sufficient to force *any quiescent finite Resistance whatsoever*.

But as this Account and *Hypothesis* are part of a Posthumous Work (if a liberty of Conjecture may be allow'd in so uncertain a matter,) I shou'd suspect, that these Papers were left unfinished by *Borellus*; or at least, that in many places the last hand was never put to 'em. For, neither in this Place, nor any other of this Work, does he account for any more than the *Systole* of the Heart, and the resistance which is made to the Progressive Motion of the Blood in the Arteries only. This alone he found to exceed the Power of the Heart so prodigiously, that he seems to shuffle it off his hands with a general and precarious Solution, as a difficulty that he was desirous to be rid of. For, having ascrib'd this *stupendous* (as he himself calls it) effect to the *Energy of Percussion*, he takes no care to satisfy his Reader any farther about it, or to refer him, or give him the expectation of satisfaction any where else; altho he has an express Treatise on the *Force of Percussion*, which was written preparatory to this, and to which he frequently refers in other Places of this Work. But what confirms my suspicion, that this part was intended for a farther Revise by the

the Author, is, that he has left the Progress of the Blood thro the Veins, and the *Diastole* of the Heart, absolutely un-touch'd, tho they are difficulties of a much greater Magnitude, than this which he has attempted to account so slightly for. For, in these he is excluded the benefit of *Percussion*, and has yet a greater resistance to overcome without it. Omissions of this kind are so unusual with this Author, where-ever he knows himself to go upon sure grounds, that it is to me an Argument, that he doubted the sufficiency of his *Percussion*, and reserv'd these important *Phænomena* for farther consideration, without plunging himself into such an Absurdity as to ascribe to *Percussion* any such *Energy* as to be able (so broken as it returns to the Heart) by its re-action to force that Power, from whence only it was at first deriv'd.

Dr *Lower* and Mr *Comper* deliver their Opinions of the Cause of the Dilatation of the Heart so very short, and without any Arguments to support 'em, that by exposing 'em naked, they seem rather to discourse of it transiently, as men obliged by the nature of their Subjects to say something of it, than solicitous to give any full or satisfactory Account, and therefore I shall proceed no farther upon 'em here.

But tho the *Hypothesis* of *Borellus* may in this case be found precarious or insufficient (a misfortune that has befallen him in divers other particulars) his *Theory* holds still good. At least it ought to be allowed in justice to his great Abilities and Exactness, till some body convicts him of some material Error in his Calculations, which has not as yet been done by any body, that I know of.

Supposing then the Force of the Heart, and of the *Muscular* Coat of the Arteries, as likewise of the resistance, which they must overcome, to be computed with any degree of accuracy, there remains yet such a prodigious disproportion to be accounted for, as requires some more powerful Agent, than any yet assign'd, to make up the deficiency.

What assistance the Heart receives from the action of the *Thorax* towards the facilitating its contraction, without which assistance there could have been no *Systole*, has been already shewn. But neither the *Intercostal* Muscles, or *Diaphragm*, which are so instrumental in that part of its action, can contribute any thing to the *Diastole*; because they serve only to enlarge the cavity of the *Thorax*, and thereby to open a Passage to the Blood from the Heart, and promote its Constriction.

Whatever therefore the Force is, that dilates the Heart, and is the Cause of the *Diastole*, it must be equal to that of the Heart, the *Intercostal* Muscles and *Diaphragm*; to all which it acts as an Antagonist. I take no notice of the *Serratus Major Anticus*, and other Muscles, which have an obscure share in the *Elevation* of the *Costæ*, because as much may reasonably be deducted upon the account of the *Obliquus externus Abdominis*, and other Muscles; which, having their insertions on some of the lower *Ribs*, are as instrumental towards the *Depression* of 'em, and so ballance the account. But the chief use of these is in violent Respiration. In ordinary Respiration their share is small.

Such a real Power (which may in the least be suspected of any share in this Action) is hard, perhaps impossible to be found in the *Machine* of any *Animal* Body; and yet without some such Antagonist, it is as impossible the Circulation of the Blood shou'd be maintain'd. All the Engines yet discover'd within the Body conspire towards the *Constriction* of the Heart, which is the *State* of *Quiescence*, to which it naturally tends. Yet we find it alternately in a *State* of *Violence*, that is, of *Dilatation*; and this upon necessity, because upon this *Alternation* depends all Animal Life.

Some sufficient Cause external must therefore be found, to produce this great Phænomenon, which Cause must be either in the *Air*, or *Atmosphere*, because we have no constant and immediate Commerce with any other *Mediams*.

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Some great Physicians observing this, and that depriv'd by whatsoever Means of Communication with the *external* Air, we became instantly extinct, have imagin'd, that in the Act of Inspiration certain purer parts of the Air mixed with the Blood in the Lungs, and was convey'd with it to the Heart, where it nourish'd a sort of *Vital Flame*, which was the cause of this reciprocal *Æstus* of the Heart. Others not quite so gross, rejecting an *Actual* Flame, have fancied that these fine Parts of Air mixing with the Blood in the Ventricles of the Heart, produc'd an *Effervescence* which dilated it. But these Fancies have been long since exploded and condemn'd upon ample Conviction, and 'tis a Point yet undetermin'd, whether any Air does mix with the Blood at all in the Lungs, or not.

But supposing that some Air may insinuate it self into the *Pulmonary Vein*, it can no other way dilate the Heart than by an *Effervescence* in the Left Ventricle, which wou'd not dilate the Right. But this opinion is contradicted by *Autopsie*, and too laboriously confuted by others, to be brought upon the Stage again here.

There remains therefore only the *gross Body* of the *Atmosphere* to be consider'd, which is undoubtedly the *true Antagonist* to all those Muscles, which serve for ordinary Inspiration and the Constriction of the Heart. This will appear more evidently, if we consider not only the Power, but the necessity of its Action upon *Animal Bodies*, as well as the want of other sufficient Agents.

The Heart is a *Solitary* Muscle of very great strength, and the *Intercostal* Muscles and Diaphragm, which likewise have no *Antagonists*, are a vast additional Force, which must be ballanc'd by the contrary action of some equivalent Power or other. For, tho the Action of the *Intercostal* Muscles be voluntary, that does not exempt 'em from the condition of all other Muscles serving for *voluntary* Motion, which wou'd be in a State of perpetual contraction, notwithstanding any Influence of the Will, were it not
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for the libration of *Antagonist* Muscles. This libration between other Muscles is answer'd by the *Weight* of the incumbent *Atmosphere*, which presses upon the *Thorax* and other Parts of the Body. And, as in all other voluntary Motions the influence of the Will only gives a Prevalence to one of two Powers before equilibrated, so here it serves to enable those Muscles to lift up a Weight too ponderous for their strength not so assisted ; and therefore as soon as that assistance is withdrawn, the *Costæ* are again depress'd by the meer *Gravitation* of the *Atmosphere*, which would otherwise remain elevated thro the natural tendency of those Muscles to contraction.

This is evidently prov'd from the *Torricellian* experiments, and those made upon Animals in *Mr Boyle's* Engine ; where, as soon as the Air is withdrawn, and the *pressure* thereby taken off, the Intercostal Muscles and Diaphragm are contracted, and the Ribs elevated in an instant, and can't by any power of the Will be made to subside, till the Air is again let in to bear 'em forcibly down.

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It were scarce worth while to take notice here of a Mistake of the Learned *Dr Willis*, were it not for the Great Authority of the Man, which is almost sufficient to keep Error in countenance. The Dr having observ'd that the Fibres of the *External* and *Internal Intercostal* Muscles ran in a contrary order, as it were, decussating each other, takes occasion from thence to fancy, that there was an opposition in their Office, and that as the *External* serv'd to raise up the Ribs, the *Internal* drew 'em down again, forgetting at that time, That, when a contractile Body is fasten'd at the several ends to Points unequally movable, let the Contraction happen in what part or manner soever, the more movable Point must be drawn towards the less movable : By which rule, whether *External* or *Internal Intercostals* be contracted, the lower Ribs will be forc'd to approach the upper, that is, be rais'd up.

As in the Elevation of the *Coffæ*, the Blood, by the passage that is open'd for it, is in a manner sollicit'd into the Lungs, so in the Depression of 'em, by the subsidence of the Lungs and the Contraction of the Blood Vessels, both which are consequent thereof, the Blood is forcibly driven, as it were with an *Embolum*, thro the Pulmonary Vein into the Left Ventricle of the Heart. And this, together with the *general Compression* of the *Body* by the *weight* of the *Atmosphere*, which surrounds and presses upon the whole Surface of it, is that Power which causes the Blood to mount in the Veins, after the force impress'd upon it by the Heart is broken and spent, and which is sufficient to force the Heart from its natural State to dilatation.

He that is able to compute the weight of a Column of Air, equal to the Surface of the whole Body, will readily grant it a Power sufficient for the Effects, which are here ascrib'd to it. And, when he considers, that the Bodies of Animals are compressible Machines, he will find that it must of necessity affect them in the manner here laid down. But tho our Bodies be entirely compos'd of *Tubuli*, or Vessels fill'd with Fluids, yet this Pressure, how great soever, being equal, cou'd have no effect upon 'em, if the superficial Dimensions were not easily variable; because being compress'd on all parts with the same degree of Force, the contain'd Fluids cou'd not any where begin to recede, and make way for the rest to follow, but wou'd remain as fixt and immovable as if they were actually solid. But by the Dilatation of the *Thorax*, room is made for the Fluids to move, and by the Coarctation of it fresh motion is impress'd, which is the main Spring whereby the Circulation is set and kept going.

This reciprocal Dilatation and Contraction of the Superficial Dimensions of the Body seems so necessary to Animal Life, that there is not any Animal so imperfect as to want it, at least none to the inward Structure, of which our Anatomical Discoveries have yet reach'd. For, the
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most kinds of *Fish*, and *Insects*, wants both *moveable* Ribs, and Lungs, and consequently have no dilatable *Thorax*, yet that want is made up to 'em by an *Analogous* Mechanism, answering sufficiently the Necessities of their Life.

Those *Fishes*, which have no Lungs, have *Gills*, which do the *Office* of Lungs, receiving and expelling alternately the Water, whereby the *Blood Vessels* suffer the same Alteration of Dimensions, that they do in the Lungs of more perfect Animals.

The Lungs or *Air Vessels* of *Insects* are yet exceedingly more different in Structure, Distribution and Scituation from those of perfect Animals, than those of *Fishes* are, and yet in their Use and Action agree perfectly with both, that is, *receiving* and *expelling* the Air, and *varying* the *Dimensions* and *Capacities* of the *Blood Vessels*. These having no *Thorax*, or separate Cavity for the Heart and Air Vessels, have the latter distributed thro the whole Trunk of their Bodies, by which they communicate with the *External Air* thro several *Spiracula* or *Vent Holes*, to which are fasten'd so many little *Tracheæ*, or Wind-pipes, which thence send their Branches to all the Muscles, and *Viscera*, and seem to accompany the Blood Vessels all over the Body, as they do in the Lungs only of Perfect Animals. By this disposition in every *Inspiration*, the whole Body of these little Animals is inflated, and in every *expiration* compress'd, and consequently the Blood Vessels must suffer a *vicissitude* of Extension and Contraction, and a greater motion must thereby be impress'd upon the Fluids contain'd in 'em, than the Heart, which does not in these Creatures appear to be Muscular, seems capable of giving.

The only Animal that is exempted from this necessary condition of *Breathing*, or *receiving* and *expelling alternately some fluid* into and out of the Body, is a *Fœtus*. But this, while included in the Womb, has little more than a *vegetative* Life, and ought scarce to be reckon'd among the number of *Animals*. For, were it not for that small share
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of *Muscular* Motion, which it exercises in the Womb, it might without absurdity be accounted for as a Graft upon, or Branch of the Mother.

Concerning the immediate matter, and means of Life, and Nutrition, Authors are not agreed, nor is it the business of this place to reconcile, or decide their differences, but to account for the motion of the Blood thro' the Vessels only. In order to this, it will be necessary to observe, that the Pulsation of the Heart in a *Fœtus* is so very weak and obscure, and the motion of the Blood so extream slow and languid, as to be scarce, if at all, perceivable, as has been experienc'd in the Dissection of Puppies before Respiration had. To produce such a feeble Palpitation, and creeping Motion, no greater force seems to be requir'd than may be deriv'd from the Communication between the Vessels of the Mother and *Fœtus* in the *Placenta*. I am not ignorant, that divers very Learned Anatomists (whom the Crowd have implicitly follow'd) have absolutely reject'd all Communication between these Vessels. But, with submission to Great Authorities, I think they have acted arbitrarily, and without sufficient Warrant from Reason or Experiment. For neither are the Arguments which they bring against it conclusive, nor the Office which they assign to the Umbilical Vessels in lieu of it, proper, or natural to those Vessels, or the reality of the Fact made out by any substantial Reasons. Those that reject this Communication usually do it in favour of one or both of these Opinions, that the Arteries of the *Uterus* do deposite a Nutritive Juice, or a Juice impregnate with Air in the *Placenta*, which is suck'd in by the *Umbilical* Vein, and convey'd to the *Fœtus*, for the necessary Uses of Nutrition and Life. Now those that patronize either of these Opinions lead Nature an unnecessary dance. For if the *Maternal* Blood does really contain any such *Nutritious*, or any such necessary *Aerial* Particles, why shou'd they be separated and extravasated, to be with difficulty receiv'd into the *Umbilical* Vein, and again mixt with

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the Blood, when they might more easily have been imparted by the plain simple way of Transfusion from the Arteries of the *Mother* to the Veins of the *Fœtus*. And, that this is the course which Nature takes in this case, I am perswaded from the easiness and simplicity of the Method, which readily performs what might be perhaps in vain expected from t'other, and wou'd over and above find 'em, what they seem to grope so blindly about for, a first Mover of the Blood in a *Fœtus*.

Those that contend for the conveyance of a *Nutritious* Juice, thro the *Umbilical* Vein from the *Placenta*, are forc'd upon two difficulties next to Absurdities. For first, they are oblig'd to make this Vein, which, as all other Veins, seems dedicated to the re-conveyance of Blood only, the proper and immediate Channel, thro which a very different Liquor is to be carried ; and next to give a Power of Attraction or Suction to it ; because the *Nutritious* Juice, which it is thus destin'd to carry is both Viscous and Stagnant, and has neither force to drive, nor subtilty to penetrate, or insinuate it self into the Capillary Veins ; and therefore must be drawn or suckt as *Milk* is from the *Breast*, to which the *Placenta* and its *Nutritious* Juice are by the favourers of 'em expressely compared. But if this were the sole use of the *Placenta*, and *Umbilical* Vessels, why were the *Umbilical Arteries* sent along with the Vein ? Their business is not to bring any thing back to the *Fœtus*, nor can they contribute any thing to the benefit of the *Mother* ; for the *Uterine* Arteries bring all to the *Placenta*, the *Umbilical* Vein carries it to the *Fœtus*, and the *Uterine* Veins convey back again the Surcharge of the *Mothers* Blood ; the *Umbilical Arteries* only, have nothing to do, and are superfluous and impertinent, which is contrary to the constant practice of Nature. Yet if *Autopsie* did in the least countenance this Hypothesis, some defence might still be made ; but we find in the *Umbilical Vein* of a *Fœtus* nothing but *Florid* Blood, such as in all probability it received immediately

mediately from the *Arteries* of the *Mother* without any mixture. And therefore I can't help concluding, that this opinion engages its favourers in some Absurdity, without Necessity and without Proof.

They that from the *Placenta* supply the Body of the *Fœtus* with *Air*, are as much distress'd as t'other, for they are forc'd to beg the question twice, which, even when granted, will not answer their ends. First, they suppose, that an intimate mixture or confusion of *Air* with the *Blood*, is necessary for the support of Animal Life, a *Postulatum*, which perhaps the former part of this Discourse may have render'd unnecessary ; and next that the *Fœtus* is supplied with *Air* from, and its *Blood* mixt with it in the *Placenta*.

But here again they fetch a Compass without necessity or proof. For if a mixture of *Air* were necessary to a *Fœtus*, why should it be separated from the *Mothers* Blood, and not rather both communicated together, since it is so much more easie and commodious. But neither does the *Placenta* seem to be instructed and provided for the separation of *Air*, but of a much *grosser Fluid*, destin'd to some other use, which *Autopsie* confirms. Yet were both these opinions true, they are however defective, and the Circular Motion of the Blood unprovided for.

By the way of *Transfusion* this great Phænomenon is naturally accounted for, and the ends, for which the other two Hypotheses were devis'd, might both be answered with more ease. For the *Hysterick* Arteries transmitting their Blood immediately to the *Umbilical* Vein, may very easily transmit such *Nutritious Juices* or *Aerial Particles* as are contain'd in the Blood, along with it, without depositing 'em by the way. By this means so much of the Impulse of the *Mothers* Blood is preserv'd, as suffices to maintain that languid circulation, which a *Fœtus* enjoys. For the Blood being driven thro' the *Arteries* of the *Uterus* into the *Umbilical Vein*, is convey'd directly to the *Sinus* of the *Porta*,
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and thence, by a short and direct passage thro' the *Cava* to the Heart ; where passing thro the *Foramen Ovale* to the *Left Ventricle*, and thro the *Canalis Arteriosus* from the *Right* and *Pulmonary Artery*, it is all deliver'd without coming at the *Lungs*, to the *Aorta*, and from thence again by the *Umbilical Arteries* to the *Veins* of the *Uterus*, making a sort of *Epicycle* to the main Circulation in the Mother.

As this Opinion is favour'd by the structure and disposition of the Blood Vessels on both parts, so there is nothing in it difficult to be conceiv'd, or repugnant to experience. Late discoveries have made it appear, that the Arteries and Veins are continued Tubes, and that the latter contain nothing but what they receive from the former, and no reason appears why we shou'd think this Method to be varied in the *Placenta*. On the other hand, if the Arteries of the *Uterus* were continued to the Veins of the *same* part, and those of the *Fœtus* in like manner, without communicating with each other, their confluence in the *Placenta* seems to be altogether impertinent and of no use, and the *Umbilical Arteries* and Vein fram'd for no other service or purpose, than to give the Blood room for an idle Sally.

Thus the reasonableness of this old Opinion may be vindicated, but the certainty of it rests upon stronger proof. Mr *Comper*, to whose happy Industry we owe the Confirmation of many Antient Discoveries, and the benefit of some new ones, has the honour to re-establish this old, but long exploded Truth. For by pouring *Mercury* into a Branch of the *Uterine Artery* of a *Cow*, that went into one of the *Cotyledones* of the *Uterus*, he fill'd those Branches of the *Umbilical Veins*, which went from that *Cotyledon* to the *Navel* of the *Fœtus* ; which with a part of the *Uterus* he keeps prepar'd by him.

It wou'd be a weak objection, to alledge that the Observation and Experiment being made on the *Uterus* of a *Cow*, the inference wou'd not hold from thence to a *Woman*, the one being *Glanduliferous*, and the other *Placentiferous* ;
since

since ev'ry one of these *Cotyledones*, or *Uterine Glandules*, is in all respects a little *Placenta*, and all the difference between 'em is in number, name, and magnitude. Why *Ruminants* differ in this particular from other *Viviparous Animals*, is beside the subject of our present Enquiry. But the great Flux of Blood which constantly follows upon drawing the *Placenta* from Women (which is frequently so great as to cost 'em their Lives) is as plain a demonstration to Reason of the *Continuity* of the Vessels, as Mr *Comper's* Experiment is to the Eye.

I have heard it objected by very learned men, that if there were such a *Continuity* of Vessels, and such *Transfusion* of Blood, the *Fœtus* must necessarily perish thro loss of Blood, upon the separation of the *Placenta* from the *Uterus*; but that on the contrary no visible flux of Blood does follow while the *Fœtus* continues wrapt in the Membrane, in which condition it may be kept alive some hours. To this it may be answer'd, that the *Circulation* in the *Fœtus* being deriv'd from the Mother, may be suppos'd wholly to cease upon the cutting off the communication between 'em, till it is again renew'd more forcibly by *respiration*. But if we allow the Motion already impress'd upon the Blood to be sufficient to keep it going a little while, yet it must needs be so exceeding languid, that the meer resistance of the external Air must be more than enough to hinder any Efflux of Blood from a *Fœtus* before *Respiration*. How long Life may be preserv'd without an *actual* Circulation of the Blood, is a question not of this place. But we have been convinc'd by many and notorious Observations and Experiments, that Life has been recover'd a long time after all tokens of *Respiration*, *Circulation*, or even Life it self have disappear'd, so that we can't think the first solution either impossible or improbable.

I expect to be told, that in the early days of *Gestation* in *Viviparous Animals* there is no *Placenta*, or any Adhesion of the *Umbilical Vessels* to any part of the *Mother*, and consequently no such *Transfusion*; and that in *Oviparous* there is

no *continuity*, or *communication* of Vessels of any kind, during the whole time of *Incubation*.

But these Objections carry neither the Weight nor Difficulty along with 'em, that they may be suppos'd to do; for in those days there is neither *Blood* nor *Blood Vessels*, and consequently there can be no *Circulation* of the Blood; and the *Embryo*, of what Species soever, is no more than a *Vegetable* at that time; nor does the *Fætus* of any *Viviparous* Creature enjoy any *Circulation*, or shew any signs of Animal Life, till after those Vessels, as well as others requisite to the Circulation, are compleated.

It must be confess'd, that *Oviparous* Animals are denied the Benefit of this Communication: But that want is sufficiently compensated by a peculiar Mechanism, which directly answers the ends of *Respiration*, and the *Pressure* of the *Atmosphere* upon the *Fætus*. There is at the *Obtuse* end of an Egg a small Cavity fill'd with Air, which is the Succedaneous Instrument to the *Respiratory* Organs. For as soon as the Contents begin to be warm'd by the *Incubation* of the Hen, or any *analogous* Heat of *Furnace* or *Dunghil*, the several Humours of the Egg require a *Fermentative* Motion, and the Air contain'd in the *Cavity* or *Vesicle* at the *obtuse* end of the Egg is rarefied, and the Vesicle extended and enlarg'd, and consequently the other contents are compress'd; to which the *Fermentative* Motion naturally resists. But both Bodies being as well *compressible* as *dilatable*, and both having an *Expansive* Motion impress'd upon 'em by *Incubation*, the compression and renitency will be mutual; but varied in degree, according as either, thro the variation of Circumstances, shall prevail. By this means, an Alternation of Compression and Dilation will be produc'd in both answering the *Respiratory* Motion, by which a Motion will be communicated, which, as soon as the Organs by which it shou'd be regulated are compleated, will in the Body of the *Pullus* be *regular* and *circulatory*.

Fabritius ab *Aquapendente*, and after him our Great Dr *Harvey*, have assign'd divers uses to this Cavity or Air Vesicle, the Extravagance of which have perhaps deterr'd others

others from enquiring so much into the Use, as the importance of it requir'd. But tho I can't agree to that *Perpiration*, *Refrigeration*, and *Respiration*, which they make it the Instrument of, yet perhaps the *Air*, that was inclos'd in that *Cavity*, may thro the augmentation of the Body of the *Pullus*, and its own *Rarefaction* (which is at last so great as to occupy half the Shell) break the *Membrane*, which separated it from the *Pullus*, and thereby give so much *Respiration* as to form the *chirping Voice*, which is often heard before the breaking of the Shell, and with it give an Addition of Strength to enable it to break the Shell. But how it shou'd respire sooner is to me inconceivable.

There are many Problems of great seeming difficulty, the solutions of which flow naturally from what has been laid down here: But intending to prosecute this Subject farther, and to treat of the Impediments of *Respiration*, and the consequences of *Respiration* obstructed or intermitted, I shall reserve 'em for that opportunity, and content my self here to attempt the *Harveyan Problem* only, which has given abundance of Authors so much perplexity.

That incomparable Philosopher enquires, *Why a Fœtus, taken out of the Uterus with the Membranes entire, shall live in Water some hours without communication with the external Air; whereas if it be taken out and suffer'd once to breath, it can't afterwards survive a moment without the benefit of Respiration.*

Granting the Fact to be as he has deliver'd it, which yet is not so in all cases, the main difficulty is grounded on a Mistake, which from the stating of the Question I find this Great Man to have slipt into. For he thinks, that a *Fœtus* is sooner suffocated after having once breath'd, than if it had not breath'd at all, and that by breathing it had contracted something which render'd it more perishable. *Idem tamen* Harv. de Gén.-
secundis exutus, (says he) *si semel aerem intra Pulmones at-* Anem. Cap.
traxerit, postea ne momentum quidem temporis absq; eo durare de Partu.
possit, sed confestim moriatur? And presently after, *Siquidem*

constat, fetum, postquam eum semel hausserit, citius suffocari; quam cum ab illo prorsus accebat. The Dr, observing a *Fœtus* to live longer without Respiration, and to dispencc better with the want of Air while included in the Membranes entire, than it cou'd afterwards; infers thence, that the Air does in the first Act of Inspiration impress upon the Lungs some quality, which renders it ever after more indispensably necessary. But allowing his Observation, I must yet deny his Inference to be good: For, deprive a *Fœtus* of means of respiring, and then take it out of the Membranes, and it shall be as soon suffocated, as if it had respired before. This proves, that this Necessity of intercourse with the Air by way of the Lungs is not the Offspring, but the Parent of Respiration, and that, that Learned Man was drawn into a Fallacy of *Non causâ pro causâ*.

The reason of this Necessity is the pressure of the External Air upon the Surface of the Body, from which it was defended by the interposition of the Membranes and the Humours contain'd, which are not so compressible, as the Body of the *Fœtus* itself. So soon therefore as the *Fœtus* is excluded, and expos'd to the immediate contact of the ambient Atmosphere, the Vessels and all the Cavities of the Body must necessarily be so compress'd, that the Fluids can't have room for Motion, and consequently the *Fœtus* cou'd have no Life, if Nature had not contriv'd by the Motion of the *Thorax* to remove and admit that pressure alternately, and thereby to impress a Motion on the Fluids, which is the Spring of Life. But this Motion of the *Thorax* being any way suppress'd, the equal pressure of the Atmosphere on all parts occasions a total Cessation of Motion, which is Death.

I shall prosecute this Subject no farther now, nor trouble the Reader with any Apology, for dissenting from those great Men herein named: Because, I hope, I have done it with Modesty, and all the Respect due to so great Authorities, and have assign'd nothing which is not matter of Fact uncontroverted, or deduc'd from it by plain Mechanical Necessity.